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PROCESSING DEMANDS OF
KINESTHETIC INFORMATION IN SHORT-TERM MEMORY

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Processing Demands of Kinesthetic Information in Short-Term Memory" submitted by Robert Harold Sharp in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

The purpose of this study was to observe the processing demands of kinesthetic information in short-term memory. There were two factors of experimental interest: information load and interpolated task. The experimental task involved subjects manipulating a freely moving joystick to establish a number of positions, and to reproduce them sometime later.

The experimental design was a treatment by subjects, complete block, randomised design, replicated three times for each subject. Performance was measured in both mid-frontal and median planes and the basic statistical method used to analyze the data was analysis of variance.

It was concluded that:

1. Recall accuracy was an inverse function of memory load.

2. The short-term retention of kinesthetic information was not affected by the interpolation of non-verbal (kinesthetic) tasks.

3. Subjects were equally accurate in both mid-frontal and median planes.

An analysis of the data also allowed implications regarding decay and interference and the possible storage characteristics of kinesthetic information in short-term memory, to be discussed.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

It is well known that learning is improved if the performer receives some knowledge of his successive performances. Such knowledge has been termed feedback. The performer receives feedback through different sensory modalities, e.g., auditory, visual, tactile, and by augmented feedback such as verbal praise. The performer also has the potential of being aware of his movements through kinesthetic feedback, without the aid of exteroceptive cues.

The importance of kinesthesis has been stressed by many investigators, both physical educators and psychologists. Phillips (1941) mentioned that efficient kinesthesis was essential for refined performance. Morgan (1965) said that kinesthesis was an important sensory modality and that it was unquestionably an important factor in organizing behaviour.

Many investigators have discussed the role of short-term memory in the performance and acquisition of motor skills (Crossman, 1960; Fitts, 1964) and recently investigations have been directed towards the reciprocity between kinesthesis and short-term memory. Some of these investigators (e.g., Posner and Konick, 1966; Posner, 1967a) have made implications concerning the actual storage characteristics and processing demands of kinesthetic information in short-term memory.

The Problem

In order to remember verbal material efficiently, a conscious effort on the part of the individual has to be made. If the individual is distracted whilst he is making this effort then forgetting takes place. However, if the individual is remembering kinesthetic information then increased forgetting with increasing distraction may not occur. This disparity has been shown by such investigators as Posner and Rossman (1965) and Posner and Konick (1966) who used experimental paradigms which involved the subjects completing verbal transformation tasks during the retention interval.

The present study was an attempt to elucidate this disparity by observing the recall of kinesthetic information from running short-term memory when the interpolated tasks were serial, coherent, redundant, and non-verbal (kinesthetic) in nature.

Importance of the Study

In many situations, both everyday and competitive, man has to perform physically without the aid of exteroceptive cues. For example, the operator of a workshop lathe cannot use his eyes to scan the controls as they are being used to observe the work being turned, thus he must integrate information from kinesthetic and tactile receptors in order to manipulate the controls in an efficient manner. On the field of sport there are many cases where movements are initiated without visual feedback, e.g., as in swinging a golf club or a cricket bat. In these cases it is apparent that the kinesthetic sense may be a very important

source of information feedback. However, in the domain of physical education and indeed many other areas, the research related to this sensory modality is very sparse (Howard and Tempelton, 1966).

A present area of research in physical education is that associated with short-term memory. It is within this short temporal interval (in the order of seconds) that the performer has the potential of utilizing kinesthetic information for control and regulatory (feedback) purposes. Certain investigators have observed the recall of kinesthetic information from short-term memory and shown how the performer may use this information, however, their observations have also posed several questions regarding the nature of the stored material and its processing demands in short-term memory.

This writer believes that in order to develop an adequate theory of motor behaviour, a description and knowledge of the underlying component processes such as the recall of kinesthetic information from short-term memory, may be helpful.

Definition of Terms

Kinesthesis (K): Kinesthesis is the sense of positions and movements of the joints (Rose and Mountcastle, 1959).

Short-Term Memory (STM): STM has been defined by Fitts and Posner (1967) to be that memory system which loses information rapidly in the absence of sustained attention. This system is said to be in operation for the first sixty seconds after stimulus presentation. After this period the information is either lost or transferred to long-term memory.

Proactive Inhibition (PI): PI is the effect of previous activity on subsequent activity (Manis, 1968).

Retroactive Inhibition (RI): RI is the effect of subsequent activity on the retention of previous activity (Manis, 1968).

Imagery: Imagery has been defined by Posner (1966) to be a relatively direct representation of the input information which might include spatial (i.e., distance, form, and location) information and other detailed information which would not occur in a verbal description.

Mid-Frontal Plane: The mid-frontal plane is the vertical plane in which the subject can make left-right movements (Howard and Tempelton, 1966).

Median Plane: The median plane is the vertical plane in which the subject can make forward-backward movements (Howard and Tempelton, 1966).

Delimitation of the Study

The study is delimited by the number, and sex of the subjects (Ss) used.

CHAPTER II

REVIEW OF THE LITERATURE

A model of human information processing that appears most relevant to this study is one developed by Donald Broadbent (Broadbent, 1958). Some of the principles of his model most pertinent to this review are now outlined.

There are two stages within the nervous system that Broadbent called the P (Perceptual) and S (Storage) systems. The P system acts as a limited processing system of which one of its functions is to encode sensed information (Fogel, 1963), and the S system is a storage mechanism for excess information when the P system is handling as much information as its capacity will warrent. On the basis of work by Brown (1954, 1955), Broadbent suggested that information stayed in the S system only for a limited time (in the order of seconds) but after passing through the P system could be returned to the S system. Brown (1955) called this process "rehearsal".

Broadbent's model is thus one of a recurrent circuit type, i.e., information is circulated from a temporary store (the S system, henceforth referred to as STM), through a limited processing capacity system (the P system) and back again, repeated until a plan of response has been formed.

Fundamental issues have been raised about the ability of this model to account for: the factors governing loss of information from STM; the characteristics of stored information in STM and, the processing demands of different modes of sensed input in STM.

Information Loss

Decay Factors: As early as 1913, Thorndike (1913) postulated that the memory trace decayed autonomously over time, a concept that has recently been defended by Brown (1958). Brown tested the retention of consonant pairs up to four pairs, over an interval of 4.7 seconds. Ss were required to read aloud digits during the interval or else rest, the idea being that rehearsal was prevented in the former condition but not in the latter condition. As Brown predicted, retention was significantly lower when rehearsal was prevented and thus he hypothesized a decay theory of STM.

A decay theory for verbal STM has been disputed recently (Norman, 1969). Likewise, decay in motor STM is also open to question. Adams and Dijkstra (1966), Williams, Beaver, Spence, and Rundell (1969), Herman and Pepper (1970) and, Stelmach and Barber (1970) have all supported a decay hypothesis. Stelmach and Barber examined the retention of blind positioning responses over 30 seconds with interpolated conditions that were either rest or the learning of an antagonistic motor response. The antagonistic motor response in this case was a linear movement, opposite in direction to that required by Ss when moving to the criterion position. Performance decrement was found to be the same at the end of 30 seconds for both conditions and the investigators thus suggested that the forgetting must have been due to temporal decay. Adams and Dijkstra (1966) tested the retention of non-visually guided linear movements varying in length from 10 cms. to 34 cms., over retention intervals varying from 5 seconds to 120 seconds. The basic variable of interest was the

number of reinforcements (1, 6 or 15) of the movement prior to the retention interval. Both retention interval and number of reinforcements were statistically significant at beyond the .001 level. The investigators concluded that because there was forgetting over all unfilled intervals when rehearsal could have been taking place (thus maintaining the trace), that forgetting was due to memory-trace decay.

However, in the above study, the authors failed to indicate that after 15 seconds delay, performance was equally as good as after zero seconds delay. Similar patterns have been shown by Posner and Konick (1966), Posner (1967b), Stelmach (1969b) (15 seconds), and more recently by Wilberg and Sharp (1970a, b) (20 and 15 seconds respectively). The evidence appears to indicate that in a rest condition, K information does not decay within a period of about 20 seconds but is susceptible after this time (Adams and Dijkstra, 1966; Stelmach, 1969b).

Proactive Inhibition: In a study by Wickelgren (1966), Ss copied a list of PI letters, then copied a single letter to be recalled later, then copied a list of RI letters and then attempted recall of the letters one at a time. The lengths of the lists (0, 4, 8 or 16 letters) and phonemic similarity (0, 25, 50, 75 or 100% similar letters) of the PI and RI lists were varied systematically. Wickelgren found that PI increased with the length of the PI lists up to four letters and also with increased phonemic similarity between the PI list and the to-be-remembered letter. PI in verbal STM is well documented (Keppel and Underwood, 1962; Murdock, 1964, and Peterson, 1965), although PI of K information in STM has not been studied to such great depth. Ascoli and Schmidt (1969)

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manipulated the number (0, 2 or 4) and the relative size (5 or 10 cms. longer or shorter than the criterion) of movements prior to Ss making a criterion movement, with retention interval (10 or 120 seconds) as a between-Ss variable. Results indicated that the introduction of four previous responses (relative to 0 and 2) caused a significant reduction in the recall of the criterion position. They concluded therefore that PI was strong in motor STM. In a similar study, Stelmach (1969a) found PI effects for circular movements when the number of previous responses was increased. Stelmach (1969b) found that by manipulating the degree of similarity (5, 15 and 25 degrees) of prior responses about a criterion he could obtain interference effects. However, in this study, recall decrement was found to be inversely related to the degree of similarity; a finding contrary to those usually observed in verbal STM (Wickens, Born, and Allen, 1963).

Retroactive Inhibition: Conrad (1964) investigated intrusion errors in the immediate recall of lists of six letters drawn from the population B, C, P, T, V, F, M, N, S, and X. He found that letters whose pronunciation began with an "ĕ", i.e., F, M, N, S, X, tended to be confused with each other in recall and letters whose pronunciation ended with an "ē", i.e., B, C, P, T, V, also tended to be confused with each other in recall. Wickelgren (1965, 1966) has shown similar acoustic interference effects. In fact, RI effects in verbal STM have not been easy to demonstrate using dimensions other than acoustic confusability. For example, Dale and Gregory (1966) showed small effects of varying semantic similarity upon the amount of RI. Taylor et. al. (1966) showed that the formal

similarity of an interpolated task to a treble right-left alternation task had no effect on retention and Kennely (1941) also showed that formal similarity was not a significant variable affecting short-term retention.

In the area of motor STM, Stelmach and Barber (1970) concluded that interference was not a factor in the retention of kinesthetic information. They found no differential forgetting effect over 30 seconds when Ss either rested and held the handle of the response lever, or executed an antagonistic, linear motor response. This result was supported by Bilodeau and Ryan's (1960) finding that the retention of a linear motor response was similar for both "rest" and "hold" conditions. Boswell and Bilodeau (1964) presented opposing evidence showing that zeroing the lever was not detrimental to retention but retrieving a pencil from the floor was. However, it may be argued that disengagement from the task (and perhaps change of cognitive set) was a factor causing performance decrement. Evidence for RI has recently been presented by Herman and Pepper (1970). They tested STM for discrete force responses (2 and 4 lbs.) over an interval of twenty seconds. The retention interval was filled with force responses varying in relative magnitude and direction. Direction had no effect on retention but relative magnitude was highly significant. Interpolated forces greater in magnitude than the criterion force produced significantly larger recall forces than did interpolated forces of smaller magnitude than the criterion force. The authors concluded that the directional effect was due to an assimilation process. This process was not defined but it is possible that the authors were referring to the kinesthetic after-effect phenomenon.

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A recent view by Posner (1966) indicates a dual mechanism of forgetting. His "Acid-Bath" model implies that competing items in memory do not remain independent but similar items intermingle during the retention interval and destroy the trace. In other words, the interference depends on the time in store and the similarity between stored items. Wickelgren (1966) has also presented a dual process theory of forgetting for verbal STM. In the domain of motor STM, similar theories have been presented by Stelmach (1969a), Herman and Pepper (1970), and Stelmach and Barber (1970).

Storage Codes

In order that the human being may perform in a purposeful manner, he must both receive and process information in such a way that he can effect control of the real world. Because the performer can only store a limited amount of information at any one time (Miller, 1956), then for efficient and purposeful behaviour to occur, a catagorization or coding of the input information must take place (Miller, 1967). Obviously the performer must also utilize information retrieved from long-term memory, however, in the present context we are only concerned with information stored in STM.

In the performance of perceptual-motor skills the two sensory systems which appear to be the most important to the performer are the visual (V) and K systems.

Storage of Visual Information: Information sensed through the V

system can be essentially of three kinds; verbal, form, and motor.

By virtue of its nature, verbal information sensed visually loans itself to coding in verbal form. Verbal coding is very efficient for remembering as has been shown by Pollack (1953) and S.L. Smith* (1956). There is much evidence indicating that verbal information sensed by the V system is read into some form of auditory store. Conrad (1964) found that substitution errors made in recalling visually presented letters were just like those made in identifying letters spoken in a noisy background. Sperling (1963) and Wickelgren (1965, 1966) both observed auditory confusions in STM. Hintzman (1965) has presented a slightly different view. He suggested that verbal information was read into an auditory store and confusions arose as a result of articulational similarities. Hintzman stated, "...confusions are really kinesthetic confusions arising from similar muscular feedback patterns produced by subvocal rehearsal."

According to Hintzman then, verbal information sensed visually is retained in STM as a function of the K feedback derived from rehearsal. He suggested further that V information may be converted to motor programs which control muscle movements and it is the motor commands that are remembered. Sperling (1967) has proposed just such a mechanism.

The results of studies on memory for form are somewhat inconclusive (Norman, 1969). For example, Riley (1962) suggested that this kind of information was probably stored as images. Haber (1964) showed that STM for familiar forms varying along several dimensions depended on the verbal

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* This was reported by Miller (1956), but primary source was unavailable.

code employed. Clarke (1965) showed that complex forms were retained better in STM if a verbal label was available. However, the retention of less complex forms was not aided by attaching a verbal label and thus probably stored in image form.

The storage characteristics of motor information (i.e., distance, form, and location of movements) sensed visually is unclear at the present time. Posner and Konick (1966) looked at this problem by studying the retention of two different tasks. In one of the tasks (visual-location), Ss had to recall the location of a point at one of 12 positions along an 18 cm. line. Ss were given one second to view the point and then after a delay, indicate the location on an identical unmarked line. Delay intervals from 0 to 20 seconds were filled with transformation tasks involving rest, recording of digit pairs, addition of digit pairs, and classification of digit pairs into high or low and odd or even. Results indicated that delay, task, and their interaction all had significant effects upon retention ($p = .01$). In the resting condition there was little forgetting, but with the task conditions there were increased rates of forgetting as the difficulty of the transformation (as measured by information reduction) increased. Posner and Konick concluded that the retention of this kind of information was a function of the central processing capacity available, identical to results found for the retention of verbal material (Posner and Rossman, 1965). However they dismissed the idea that this kind of information was held in STM by verbal coding. They state:

> The introspective reports of the subjects obtained after the experiment indicates in all conditions the use of crude verbal labels, such as left or right of

> center, and so on. However, the use of imprecise verbal labels cannot account for the extreme accuracy found in the visual task.

Posner and Konick concluded that this kind of information was possibly held in image form and that retention was by a recycling process.

A model that accounts for V input has recently been presented by Norman and Rumelhart (1970). They say that the V signal is transformed into a sensory representation and held in a short-term sensory storage system which maintains an image of the signal for a short time (in the order of milliseconds) after the physical signal ends. This image possesses sufficient characteristics of the physical signal for the image to be later identified unambiguously. These characteristics are then coded by a "naming process" using a "sensory-memory dictionary", and stored in STM as "memory vectors." Thus a V signal may be stored as a multi-dimensional vector containing sufficient information upon which unique responses can be based.

Whether or not this model also accounts for V-motor information has yet to be shown.

Storage of Kinesthetic Information: Posner and Konick (1966) also looked at the retention of blind lever movements (kinesthetic-distance) using delays ranging from 0 to 30 seconds and the same interpolated tasks as in the visual-location task. _Ss_ made blind circular lever movements ranging from 10 to 140 degrees, and attempted replication of the movement after the delay interval. Results indicated only delay to be significant ($p = .01$). Because forgetting was evident in the rest condition and the

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amount of forgetting did not increase with interpolated task difficulty, Posner and Konick concluded that K input was stored as non-verbal imagery. The rationale supporting this inference is as follows. Because forgetting did not increase with increased interpolated activity, then whatever process sustained the information in memory it was not an active process, i.e., not a process such as verbal rehearsal. Therefore, the authors proposed that the information was stored in a non-rehearsable form, i.e., imagery.

In a later study, Posner (1967b) found similar forgetting patterns for V and K input when the information was derived from the same task. Adams and Dijkstra (1966), and Boulter (1965) also concluded that K information was retained through non-verbal imagery.

Little mention has been made of the interaction between length of movement and interpolated task conditions. Keele and Posner (1969) showed that short movements (1 to 4 inches) exhibited little loss with rest but a large loss with a classification task (same task as in the study by Posner and Konick, 1966), whereas longer movements (8 to 10 inches) showed definite forgetting with rest and little increased forgetting with classification. Wilberg and Sharp (1970a) have shown a similar paradigm, however the effect was in a reverse direction such that 16 inch movements showed increased forgetting with a key-pressing task over a rest condition, and 4 inch movements showed no difference between the two conditions. The reverse effects found in these two studies may have been because in the Keele and Posner study, inferences were based on the results of two separate studies. Never-the-less, this data does suggest that different lengths of movements may have different memory characteristics.

Processing in STM

In accord with Broadbent's model, it has not been too difficult to show forgetting effects of verbal material when interpolating with attention demanding tasks (Peterson and Peterson, 1959; Crowder, 1967a). Peterson and Peterson showed that the retention of "CCC" trigrams was seriously affected by requiring the Ss to count backwards by 3's from a number presented immediately after the trigram. Crowder showed that the retention of five-word sequences was a function of the compatability of an interpolated key-pressing task, such that a difficult (low-compatibility) key-pressing task impaired recall more than a simple one.

An important question that may be posed from Posner and Konick's (1966) study is: why does the retention of information in the V task seem to depend upon central processing capacity while in the K task it does not? Posner and Konick (1966) and Posner (1967b) concluded that information was held as non-verbal imagery, yet for the V sense, retention of the image was under the control of the central processer, whereas for the K sense retention of the image was not under the control of the central processer!

Broadbent (1958) suggested that the retention of motor movements might require less central processing capacity, "...since it gave rise to fewer reports of conscious rehearsal." However Posner and Konick (1966) stated that the stored images in their V task were retained by a recycling process, although an explanation of this process was not given. The reason for the difference in these two reports may have been because the investigators were talking of two different rehearsal mechanisms.

Norman (1969) has indicated that rehearsal may vary along a dimension of cognizance. According to this view, both Broadbent's and Posner and Konick's theories of rehearsal could be interpreted in terms of some form of subconscious recycling process.

In reply to the question posed before, Posner and Konick (1966) suggested that the retention functions for images may have been different as a result of some fundamental characteristic difference between the two modalities involved. No mention was made however as to whether the difference might have been sensory, central, or effector in origin. In an attempt to clarify the situation, Williams et al (1969) tested the retention of digital and K information with similar interpolated material. In the first of four experiments, the effect of interpolated digital activity, i.e., resting, recording, adding, and classifying of digit pairs, on the retention of six-digit sequences was tested. In the second experiment, the same interpolated tasks were used to test the retention of blind lever movements ranging from 20 to 80 degrees. In the third experiment, the retention of blind lever movements was tested using "kinesthetic" interpolated tasks which were, resting, repeated lever movements of amplitudes read from a book, and repeated sequences of three lever movements, the last being of amplitude always equal to the sum of the amplitudes of the previous two movements. In the fourth experiment these tasks were used to test the retention of the digit sequences used in the first experiment. A retention interval of 30 seconds was used in each experiment. The results of the first two experiments showed that digital interference was successful for digital retention but not for K retention. This was similar to the results found by Posner and Rossman

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(1965), and Posner and Konick (1966) respectively. The results of the third experiment revealed interference effects but that this effect was due to interference _per se_, and not task difficulty (amount of information reduced). Because of the failure of one mode of information to adversely affect the retention of the other mode of information, Williams _et al_ concluded that the neural-behavioural mechanisms for digital and K information were independent.

The results of the research to date indicates in accord with Broadbent's model that for information to be retained in STM, it must undergo a recycling process. However, this does not seem to hold for motor information sensed kinesthetically. This suggests, as Williams _et al_ concluded, that the memory processes for K input may be different from information sensed otherwise.

Attempts to date to control the central processing capacity using K interpolated tasks in the short-term retention of K information, have used tasks that require motor responses but involve decisions based on verbal codes, i.e., Williams _et al_ (1969), Posner (1967b), Wilberg and Sharp (1970a).

If K information was retained in STM by an active (recycling) process, then interpolating with a K task which involved non-verbal coding should cause a performance decrement (according to Broadbent's model). However, if no performance decrement was incurred then it would be feasible to conclude that K retention was neither a function of non-verbal or verbal (Posner, 1967b) processing demands and thus, not by an active process.

This information together with Wilberg's (1969) view that K input may be undecodable would add strong support to the notion that K information was stored in STM by imagery.

CHAPTER III

PROCEDURES

On the basis of the review of literature, the writer decided that the following procedures should be followed in order that the problem be approached in the most efficient manner. In particular, special attention had to be made with regards to the nature of the interpolated tasks and the material to be retained in memory.

Interpolated Tasks

It was necessary to define a task that could be completed without making any verbal transformations. The following two tasks were devised in order to comply with this condition. In the first task (IT 1), _S_ made circular finger movements (in any one direction) with his non-preferred hand. In the second task (IT2), _S_ made similar movements, only with a reversal of direction after each completed circle. In both of these conditions _S_ was instructed to make the movements at any speed that he wished.

In terms of information theory (Attneave, 1959), IT 1 possessed first order redundancy and IT 2 possessed second order redundancy.

Apparatus

In many studies on K STM, _S_s have had to carry out a replacement accuracy task where they have been required to remember specific distances, e.g., Boswell and Bilodeau (1964), Adams and Dijkstra (1966).

It was decided that in order to look at the problem, this kind of task could not be used to any advantage. The reasons for this are stated as follows. Because of the novelty of the interpolated tasks and the incertitude of their differential effects upon retention, it was necessary to devise a method whereby the information input load* could be manipulated. In this respect, the experiment could then be designed to detect any differences that might exist between the effects of the interpolated tasks upon retention.

A joystick of effective radius 13 inches was designed to move in two dimensions within a range of 60 degrees either side of a vertical axis (gravitational perpendicular) (see Figure 1). The axes of movement were the shafts of two variable potentiometers fixed at right angles to one another (see Figure 2). The potential drop across each potentiometer caused by joystick movement, was translated via a potential divider arrangement to a Hewlitt-Packard, model 7303A XY recorder to give a two-dimensional graphical output. This arrangement therefore allowed <u>S</u> to move his hand randomly in a certain proximal region. The information load could then be manipulated by making <u>S</u> remember a certain number of positions (or locations) within this region.

The present apparatus also had certain advantages over replacement accuracy tasks, namely that performance in two directions (mid-frontal and median planes) could be measured independently. Poulton (1963)

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*The concept of information load in this context defines the amount the <u>S</u> has to remember. The idea of information and its use in quantifying behaviour is adequately explained by Miller, 1953, and Crossman, 1964.

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defined errors in these directions to be, alignment and compensation respectively. It was thus possible to determine if there was a directional bias in recall accuracy.

The experimental procedure necessitated a tone to be heard to terminate the input phase of each trial, and this was done by sounding a tone generator. An EICO, model 377 auditory tone generator was connected to a Bogan 'Challenger', model CHB20A amplifier and a set of Telex, model ST-20 headphones. Two-way communication between _S_ and _E_ was made possible by using similar microphone-amplifier-speaker circuits. _S_ was always in a separate room from _E_ and always wore a pair of commercial ski goggles made opaque.

Experimental Design

The experimental design was a treatment by subjects, complete block, randomised design, with three replications of each treatment condition. There were two factors of experimental interest: input information load and, interpolated task. The input information load factor had three levels: (2, 4, and 8 locations). The interpolated task factor had four levels: (Immediate Recall, Rest, IT 1, and IT2). The Rest, IT 1, and IT 2 conditions all lasted for 15 seconds.

The levels of the first factor were chosen to represent varying amounts of material in memory. Miller (1956) has indicated that forgetting increases substantially when the number of items in STM is greater than seven. The levels were also chosen to increase in a log (base 2) relation.

The levels of the second factor were chosen for the following reasons:

1. To assess the difference in recall performance as a function of the interpolated tasks.

2. To assess the difference in recall performance as a function of interpolated activity (task conditions) and no interpolated activity (rest condition).

3. To assess the difference in recall performance as a function of 15 seconds delay (rest condition) and no delay (immediate recall condition).

Method

Each S was individually tested in a single session lasting approximately 45 minutes, and received verbal instructions prior to the testing. Each S remained seated in a comfortable chair throughout the entire experiment.

The apparatus was situated to the Ss' right side or left side (depending on his preferred hand) in such a way that he could move it freely anywhere within its entire range (see Figure 3).

The following events constituted a single trial. Upon hearing a tone, S held the joystick and began moving it in a series of random*, linear steps, changing direction after each movement. At the termination

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*In any given situation, the performer always optimizes on the information available to him and develops strategies to form appropriate responses (Fitts and Posner, 1967). Thus, the concept of random movement is incorrect, however, the term was used in the hope that it would guard against Ss making conscious, like movements for every trial.

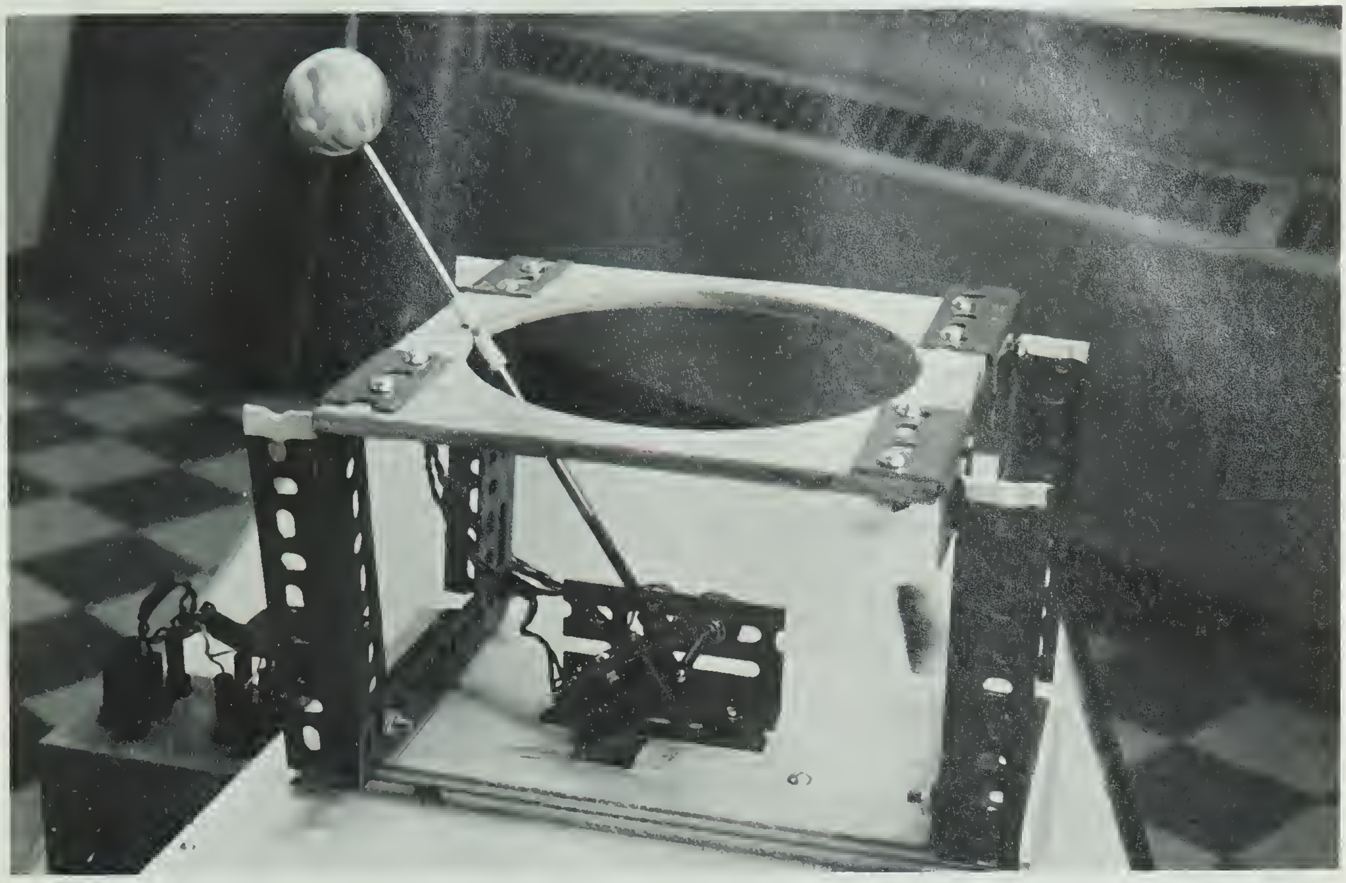

FIGURE 1 VIEW OF JOYSTICK APPARATUS

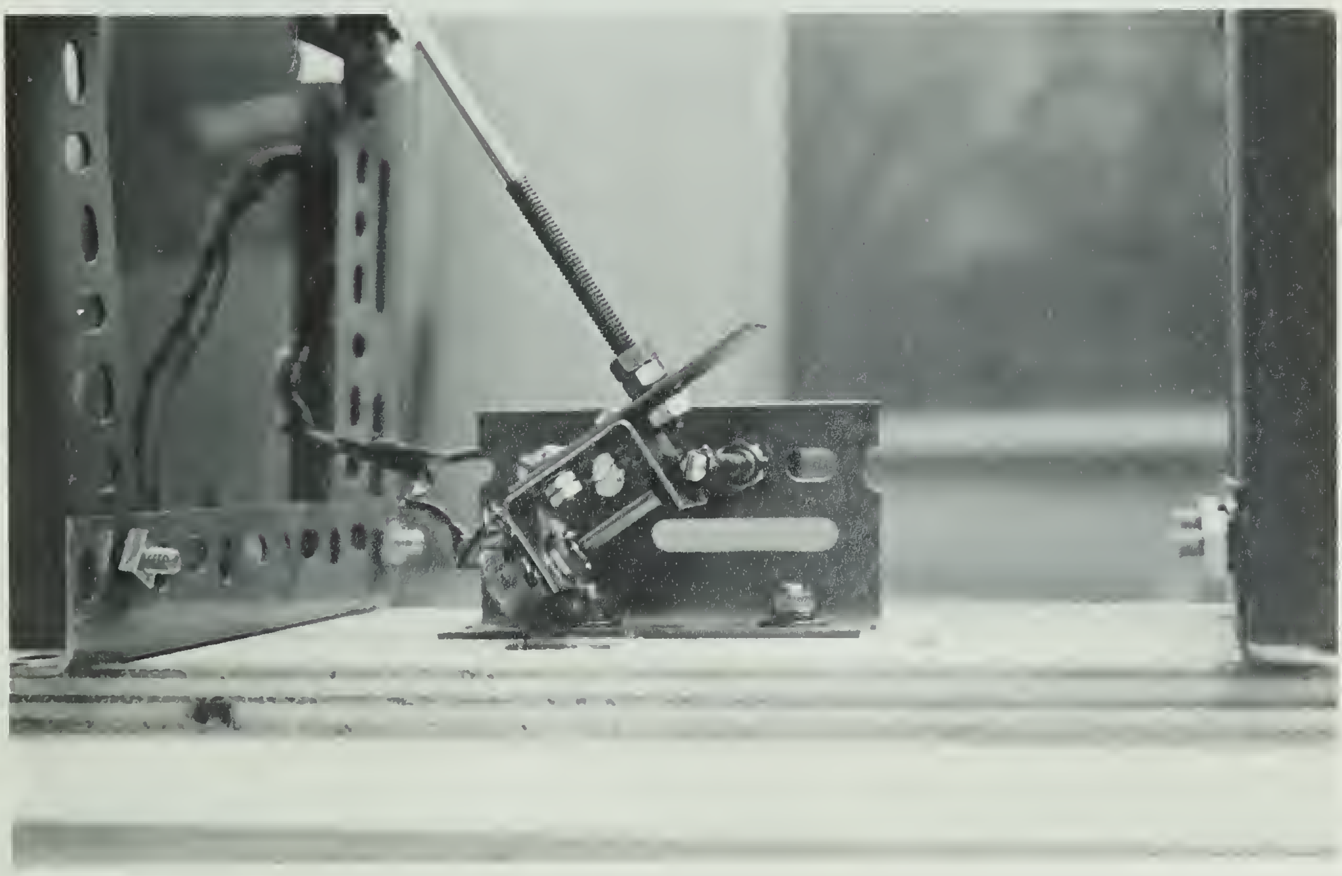

FIGURE 2 VIEW INDICATING THE AXES OF MOVEMENT OF THE JOYSTICK

FIGURE 3 VIEW SHOWING POSITION OF SUBJECT AND APPARATUS

of each step _S_ held the joystick momentarily stationary (to facilitate recording). After _S_ had changed direction eight times (thus establishing eight locations), another tone was sounded which indicated that _S_ was to cease moving the joystick and return it to the null position. At this point _S_ was told to remember the last 2, 4 or 8 locations (_E_ gave the command "Two," "Four" or "Eight" respectively). Following this command _E_ gave one of the four following commands: "Immediate," "Rest," "Task One," or "Task Two." If the command was "Immediate," then _S_ regrasped the joystick immediately and began repositioning it as accurately as possible in the same locations and same order as they were made. If the command was "Rest," then _S_ sat still for 15 seconds and attended to remembering the locations. At the end of the 15 seconds delay another tone sounded which indicated to _S_ to regrasp and reposition the joystick. If the command was "Task One," or "Task Two," then _S_ put his non-preferred hand on the table in front of him and began doing the appropriate task. A similar tone as in the other conditions indicated to _S_ when he was to stop doing the task and begin repositioning the joystick. For all trials, when _S_ had decided he had completed repositioning the joystick, he returned it to the null position and awaited the next trial.

Subjects

Twelve first year males were chosen from the population of University of Alberta, physical education undergraduates. The selection was based on the student's availability and freedom from any physical handicaps

that might have interfered with their performances.

Dependent Variables

Three dependent variables were chosen to measure performance, for reasons stated previously, and as defined in Figure 4. Only absolute error was measured and algebraic error was not taken account of.

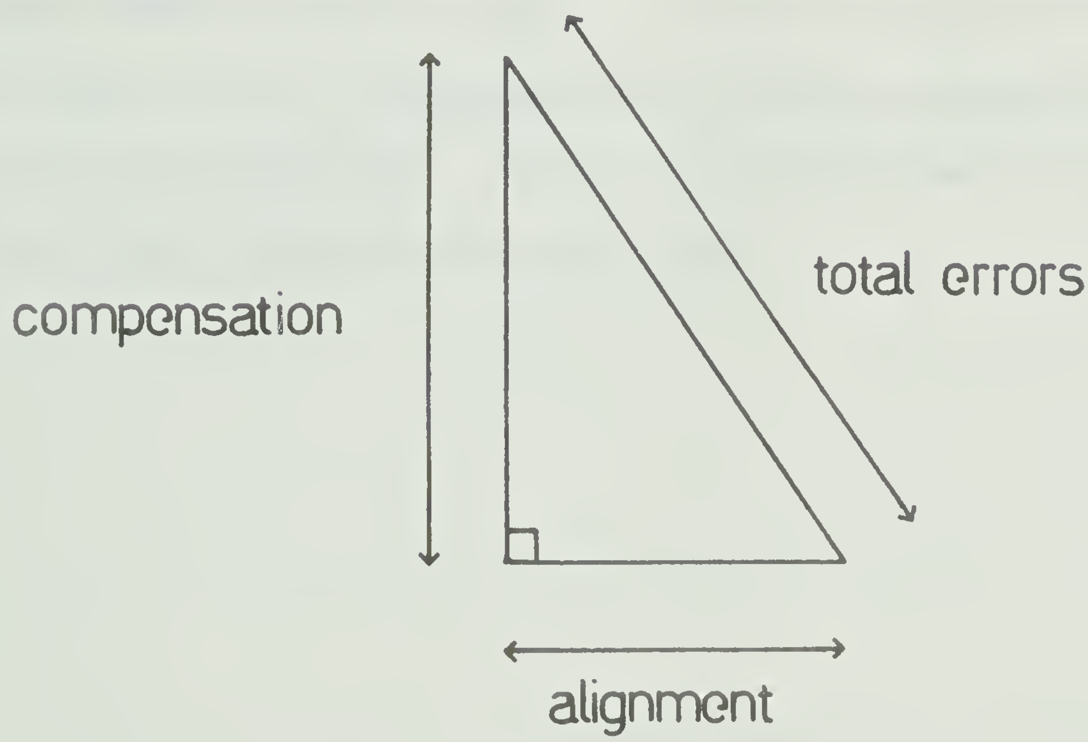

FIGURE 4 RELATIONSHIP BETWEEN DEPENDENT VARIABLES

Statistical Analysis

The data was analysed using two-way and four-way analyses of

variance. A Fortran IV ANOV80 program (an N-way analysis of variance program which utilizes the IBM Scientific Subroutine Package) was computed on the IBM 360/67 computer at the University of Alberta Computing Science Department.

A replicated design was used to gain control over individual differences between Ss and would thereby stabilize the main effects (Winer, 1962, p. 300-301). This also permitted an economy of Ss. That meaningful results can be obtained in the field of human performance using relatively few Ss has been shown by Wilberg (1969), Moyst (1969), and Hughes (1969), as well as others. In order to reduce the probability of a Type 1 error, a rejection level of 0.01 was chosen for all main effects and interactions. Duncan's New Multiple Range Test was used as the test on means for the main effects.

CHAPTER IV

ANALYSIS

Hypotheses

Two hypotheses were formulated in accordance with a review of the literature.

H_1: Errors for 2 locations < Errors for 4 locations < Errors for 8 locations.

H_2: Errors for immediate recall = Errors for rest $\leq$ Errors for IT 1 = Errors for IT 2.

The first hypothesis stated that performance decrement would be less when Ss had to remember 2 locations as opposed to 4 locations, and that performance decrement would be less when Ss had to remember 4 locations as opposed to 8 locations. In verbal STM, Lloyd *et al* (1960), Lloyd (1961), Reid *et al* (1961), and Mackworth (1964) have all shown that performance is inversely related to storage load. Using the same apparatus, Wilberg and Sharp (1970b) failed to reject a similar hypothesis.

The second hypothesis stated that performance decrement would be the same for immediate recall and rest conditions, and also that performance decrement would be the same for both interpolated task conditions. It also stated that performance decrement for the rest condition would be less than, or equal to performance decrement for the first interpolated task condition. Because of the contradictory evidence regarding decay in STM the first relation in this hypothesis could only be stated

in the null form. Although an attention demand during the retention interval has been shown to affect the retention of K information adversely (Wilberg, 1969; Wilberg and Sharp, 1970b), the effects of a coherent (and redundant) "kinesthetic" task have never been shown; thus the nature of the second relation. Because of the nature and the uncertainty of the effects of the interpolated tasks, the third relation in this hypothesis was stated in the null form. Posner (1967b) did show that tasks differing in verbal processing demands did not affect K retention differentially.

Results

Two-way analyses of variance were calculated with alignment and compensation as the criteria (Tables 1 and 2 respectively). The means for the twelve treatment conditions were each based on 36 readings for both alignment and compensation and are presented in Tables 3 and 4 respectively. The main effect of information load was significant at beyond the .001 level for both alignment and compensation (see Figure 5). The main effect of interpolated task failed to reach significance at the .01 level for both alignment and compensation (see Figure 6). The interactions between the main effects of information load and interpolated task for both alignment and compensation both failed to reach significance at the .01 level (see Figures 7 and 8 respectively).

A test of linearity and deviations from linearity was performed on the levels of the information load main effect for both alignment and compensation (Tables 5 and 6 respectively). For both dependent

[illegible]

[illegible]

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TABLE 1

TWO WAY ANALYSIS OF VARIANCE
(ALIGNMENT)

Source	df	Mean Square	F
Information Load	2	256.50	31.54**
Interpolated Task	3	3.14	0.39
Interaction	6	2.86	0.35
Error	420		

TABLE 2

TWO WAY ANALYSIS OF VARIANCE
(COMPENSATION)

Source	df	Mean Square	F
Information Load	2	190.00	30.67**
Interpolated Task	3	3.78	0.61
Interaction	6	4.00	0.65
Error	420		

CRITICAL F VALUE

df	.01	.001	
2,420	4.66	6.91	**significant at .001 level

TABLE 3

MEAN ERROR FOR THE TWELVE EXPERIMENTAL CONDITIONS - ALIGNMENT

	Immediate	Rest	IT 1	IT 2	Grand Mean
2 Locations	1.33	1.55	1.95	1.99	1.71
4 Locations	2.31	2.38	2.51	2.19	2.35
8 Locations	4.56	4.05	4.63	4.23	4.37
Grand Mean	2.73	2.66	3.03	2.81	2.81

TABLE 4

MEAN ERROR FOR THE TWELVE EXPERIMENTAL CONDITIONS - COMPENSATION

	Immediate	Rest	IT 1	IT 2	Grand Mean
2 Locations	2.39	2.01	2.36	2.32	2.27
4 Locations	2.38	3.23	3.01	2.65	2.82
8 Locations	4.55	4.73	4.70	3.89	4.47
Grand Mean	3.11	3.32	3.35	2.96	3.18

TABLE 5

TEST OF LINEARITY AND DEVIATIONS FROM LINEARITY
(ALIGNMENT)

Source	df	Mean Squares	F
Linear Regression	1	509.44	62.66**
Deviations	1	3.56	< 1
Within Trials	420	8.13	

TABLE 6

TEST OF LINEARITY AND DEVIATIONS FROM LINEARITY
(COMPENSATION)

Source	df	Mean Squares	F
Linear Regression	1	348.48	56.30**
Deviations	1	31.51	5.09
Within Trials	420	6.19	

CRITICAL F VALUE

df	.01	.001
1,400	6.70	10.83

**significant at .001 level

TABLE 7

DUNCAN'S NEW MULTIPLE RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 3 MEANS FOR INFORMATION LOAD - ALIGNMENT

	2	4	8	Shortest Significant Range
Mean	1.71	2.35	4.37	
1.71		0.64	2.66*	$R_2 = 0.754$
2.35			2.02*	$R_3 = 0.786$

*significant at the 0.01 level.

TABLE 8

DUNCAN'S NEW MULTIPLE RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 3 MEANS FOR INFORMATION LOAD - COMPENSATION

	2	4	8	Shortest Significant Range
Mean	2.27	2.82	4.47	
2.27		0.55	1.65*	$R_2 = 0.754$
2.82			2.20*	$R_3 = 0.786$

*significant at the 0.01 level.

TABLE 9

TEST OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN THE MEANS FOR ALIGNMENT AND COMPENSATION

	Mean	Standard Error of the Difference	df	t
Alignment	2.81	0.19	862	1.91
Compensation	3.18			

CRITICAL t VALUES

df	.01	.05
∞	2.33	1.64

TABLE 10

EXCERPTS FROM FOUR WAY ANALYSIS OF VARIANCE
(ALIGNMENT)

Source	df	Mean Square	F
Subjects	11	25.32	3.37*
Replications	2	9.05	1.21
Error	253	7.51	

TABLE 11

EXCERPTS FROM FOUR WAY ANALYSIS OF VARIANCE
(COMPENSATION)

Source	df	Mean Square	F
Subjects	11	21.53	3.46*
Replications	2	6.83	1.11
Error	253	6.17	

CRITICAL F VALUE

df	.01	
11,253	2.33	*significant at .01 level

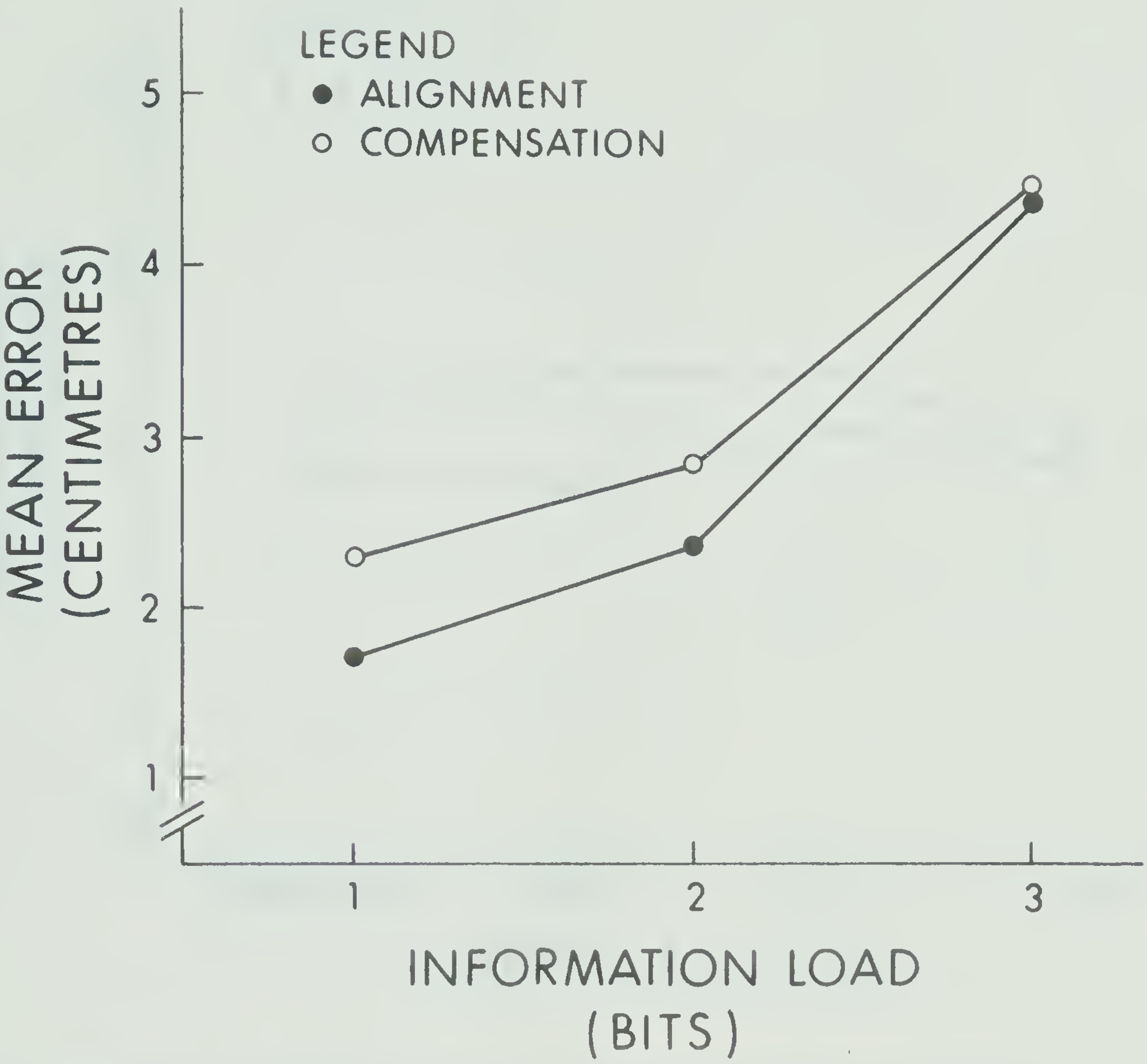

FIGURE 5 THE MEAN ERROR FOR THE MAIN EFFECT OF INFORMATION LOAD FOR ALIGNMENT AND COMPENSATION

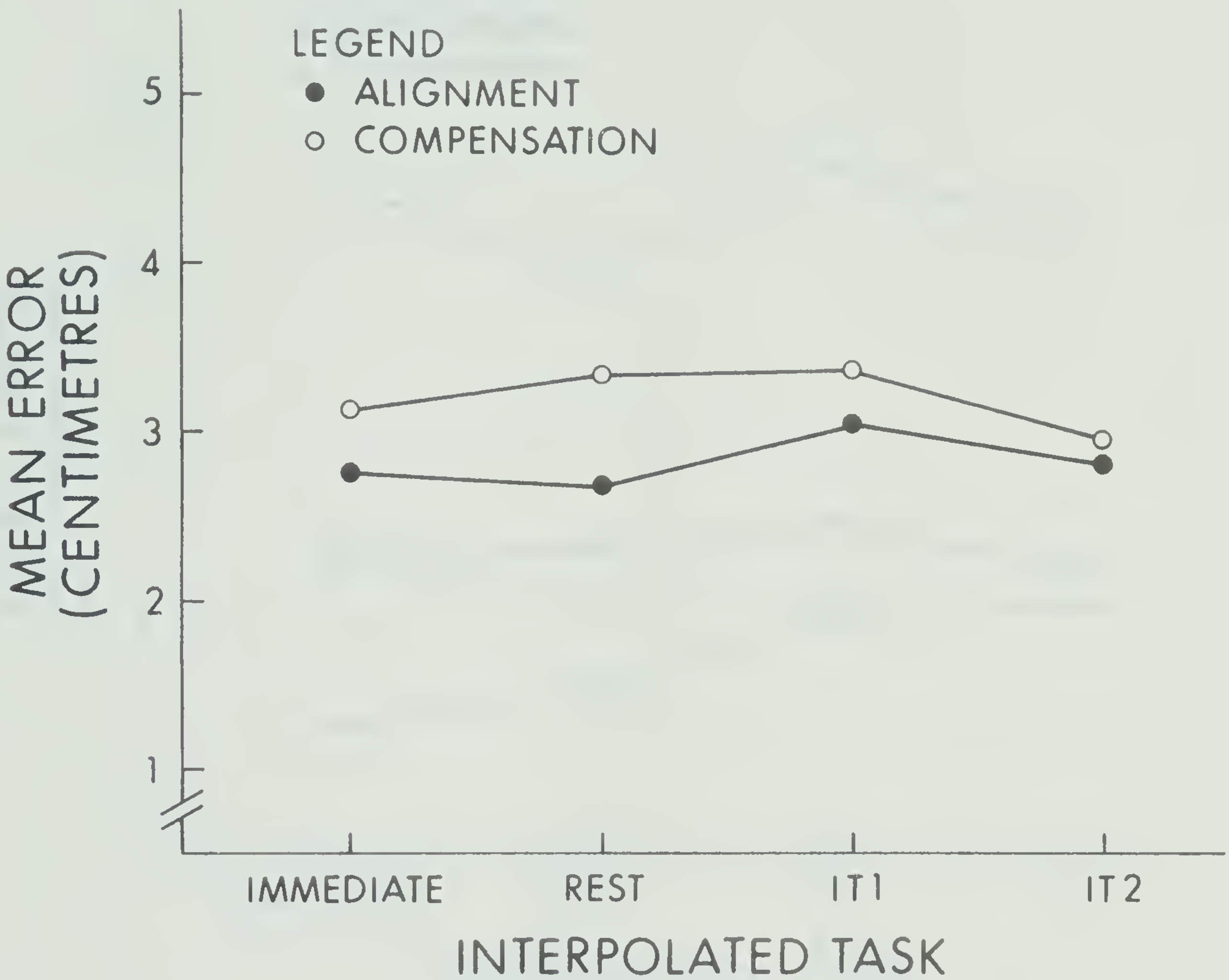

FIGURE 6 THE MEAN ERROR FOR THE MAIN EFFECT OF INTERPOLATED TASK FOR ALIGNMENT AND COMPENSATION

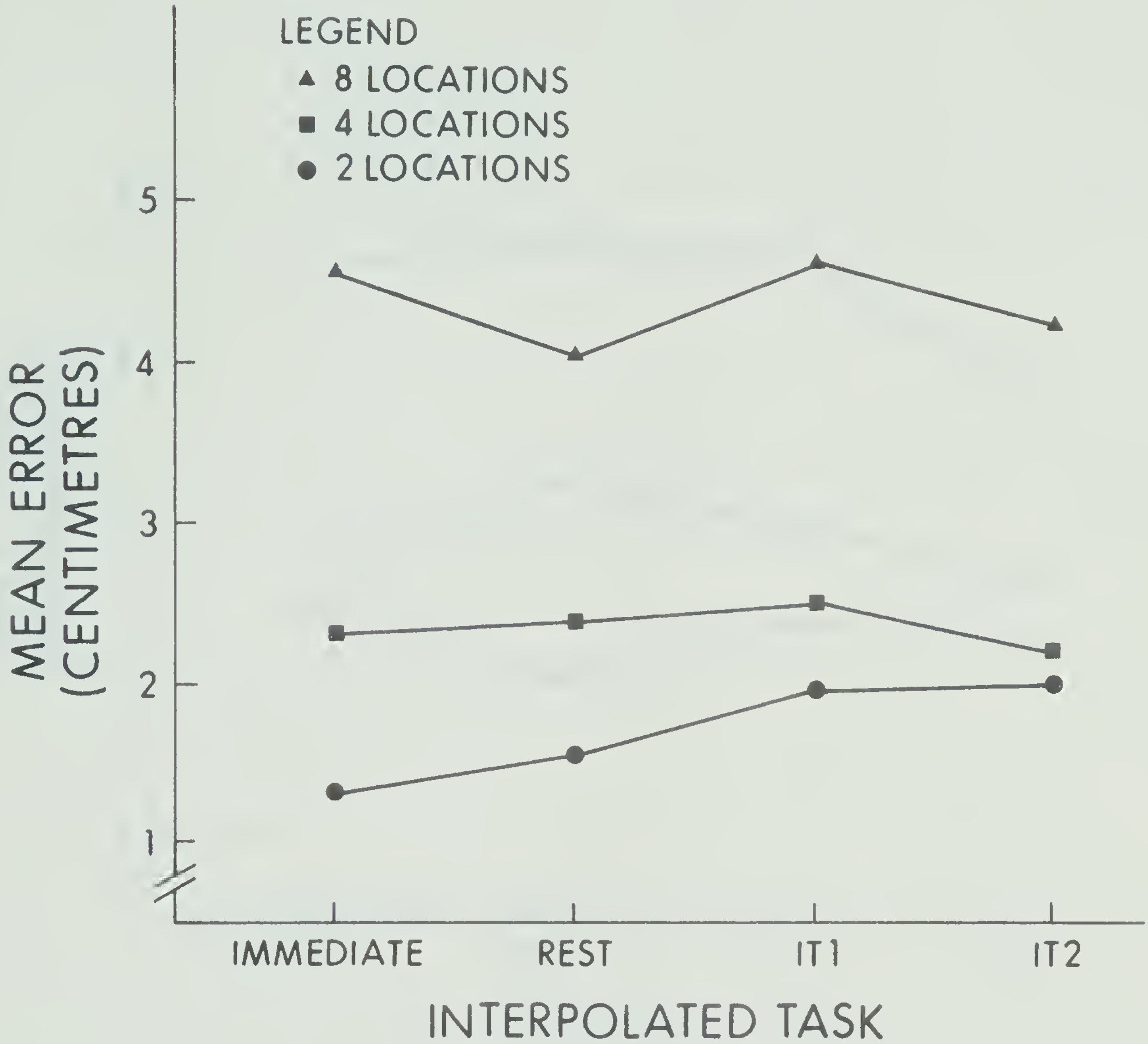

FIGURE 7 THE MEAN ERROR FOR THE INTERACTION BETWEEN INFORMATION LOAD AND INTERPOLATED TASK - ALIGNMENT

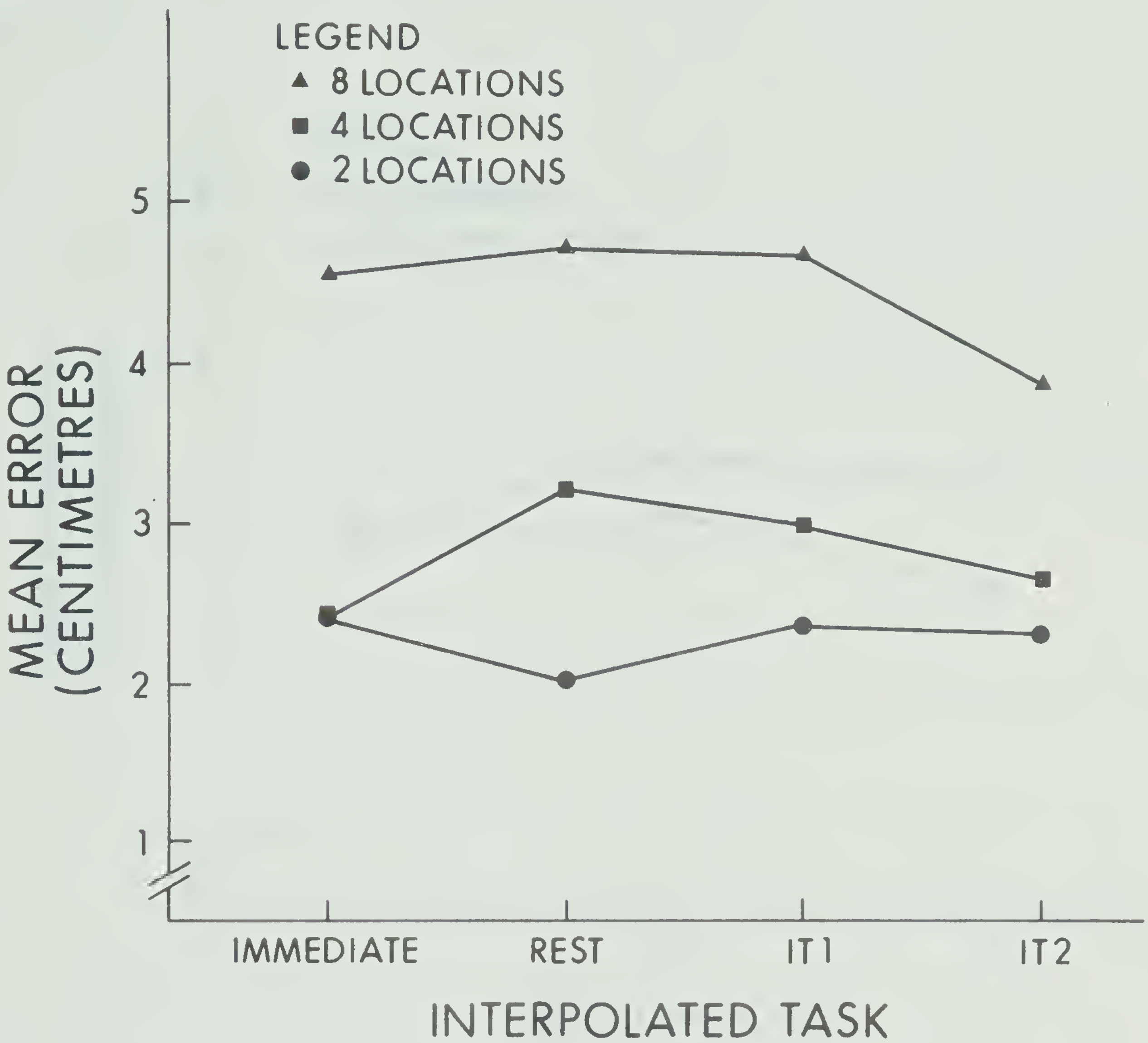

FIGURE 8 THE MEAN ERROR FOR THE INTERACTION BETWEEN INFORMATION LOAD AND INTERPOLATED TASK - COMPENSATION

FIGURE 9 THE MEAN ERROR FOR REPLICATIONS FOR ALIGNMENT AND COMPENSATION

variables there was a significant linear trend in the means ($p = .01$) whilst deviations from linearity were non-significant.

Duncan's New Multiple Range Test was applied to the means of the levels of the information load main effect for alignment and compensation (Tables 7 and 8 respectively). For both dependent variables, the mean error for 8 locations was significantly different from both the mean errors for 2 and 4 locations ($p = .01$). The mean errors for 2 and 4 locations failed to differ at the .01 level of significance for both alignment and compensation.

A $\underline{t}$ test for correlated samples was performed on the means for alignment and compensation and failed to indicate a significant difference at the .01 level (Table 9).

Four-way analyses of variance were calculated to determine the main effects of subjects and replications (Tables 10 and 11 respectively). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test these main effects. For both alignment and compensation, subjects was a significant source of variation ($p = .01$) whilst replications was not (Figure 9).

Discussion

Information Load: The results obtained for the main effect of information load for alignment and compensation were in accord with the first hypothesis and indicate that recall accuracy is inversely related to memory load. Wilberg and Sharp (1970b) found a similar decline in accuracy with increased memory load and this finding is also consistent

with those usually observed in verbal memory studies, i.e., Lloyd _et al_ (1960), Lloyd (1961), Reid _et al_ (1961), and Mackworth (1964).

Tests of linearity (see Tables 5 and 6) showed linear trends in the means for 2, 4, and 8 locations. From an information theory viewpoint, this indicates a linear, inverse relation between accuracy and information load (1, 2, and 3 bits).

Information Loss: The results obtained for the main effect of interpolated task for alignment and compensation were in accord with the second hypothesis. The fact that performance was similar for both immediate recall and rest conditions would suggest that a decay theory for K information in STM was not appropriate to account for performance decrement. Brown (1958) suggested that information in STM decayed autonomously over time unless it was rehearsed. Herman and Pepper (1970) have indicated that K information can only be rehearsed overtly (by repeating the task), and this was not allowed in this study. On the basis of these two notions, if decay was occurring then there should have been increased forgetting over rest as opposed to immediate recall, and this was not found. Similar effects to support this hypothesis have been found by Carre (1969), Dukes (1970), Hughes (1969), and Wilberg (1969), who all reported no increased forgetting between zero and ten seconds.

The design of the interpolated tasks made it possible to speculate on interference factors in forgetting as well as decay factors. Ascoli and Schmidt (1969), Stelmach (1969a, b), and Herman and Pepper (1970) have all demonstrated interference of K information in STM when the

nature of the interfering material has been similar to that in memory. In the present study, the nature of the interpolated task was circular and the nature of the input material was linear, and results indicated no increased forgetting between 15 seconds rest and 15 seconds interpolation. This suggests that there was no interference effect of the interpolated tasks. In other words, there was no interference when the potentially interfering material was dissimilar in nature to that in store. This adds support to the hypothesis that interference can only occur when the interfering material is similar in nature to that in store.

Storage and Processing: The principle reason for using the interpolated tasks IT 1 and IT 2 in this study, was so that the effects of 100% redundant, kinesthetic (non-verbal) tasks on K information in memory could be assessed.

IT 1 and IT 2 were designed specifically to be non-verbal in nature, and thus entirely different from interpolated tasks used in previous studies, e.g., Posner and Konick (1966), Herman and Pepper (1970), Williams, Beaver, Spence, and Rundell (1969). However, in order for them to be non-verbal they had to be coherent and redundant, and therefore from an information theory viewpoint they were similar tasks. However, the difference lay in their degree of redundancy*. As

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*Posner and Konick (1966) were able to quantify the effects of their interpolated tasks because of their verbal nature, but it was impossible to do so in this case because of the non-verbal nature of the tasks. In order to do so would have meant making some verbal association which would have made them verbal transformation tasks, thus defeating the object of their use.

was indicated previously IT 1 was such that it possessed first order redundancy and IT 2 was such that it possessed second order redundancy. It was the writer's belief that this qualitative difference would pose a difference in non-verbal processing capacity demands.

Using Broadbent's limited processing capacity model it was considered that if kinesthetic (non-verbal) information was retained in STM by a recycling process, then interpolating with tasks requiring different amounts of non-verbal processing capacity, should cause a difference in their effects upon retention. Conversely, it was considered that if no differential effect was found then the retention of K information in STM would not have been by a recycling process.

An analysis of the main effect of interpolated task indicated no difference between the effects of IT 1 and IT 2 (see Tables 1 and 2, and Figure 6). Posner and Konick (1966) found that the loss of K information from STM was the same regardless of the amount of interpolated verbal information processing that took place in the delay interval. They therefore concluded that the retention of K information in STM did not require central processing capacity (because of the way it was coded), otherwise increased forgetting with increased interpolated information processing would have been found. This writer believes that the present investigation substantiates this theory by demonstrating that the loss of K information from STM is not dependent upon the effects of non-verbal interpolated tasks which are similar in nature but different in degree of redundancy.

Thus, it can be argued that whatever process sustains K information in STM, it does not rely on central processing capacity. This notion,

plus the absence of decay over time found in this study and by others, e.g., Adams and Dijkstra (1966), Posner (1967b), suggests that the short-term retention of K information is a very stable function. Several writers have suggested that this is due to the coding process. Adams and Dijkstra (1966), Boulter (1965), and Posner and Konick (1966) all suggested that K information was coded in image form.

Directional Accuracy: A _t_ test for correlated samples was calculated to determine if there was a speed accuracy trade-off in accuracy (see Table 7). The test indicated a non-significant difference at the .01 level which made possible the conclusion that _Ss_ were equally accurate in both mid-frontal and median planes. Siddall, Holding, and Draper (1957) found similar results and Brown, Knauft, and Rosenbaum (1948) found that errors of extent far exceeded those of direction. In the present study the physical constraints of the apparatus allowed only a relatively small range of movement, and thus it is possible that an increase in this range may have produced a significant difference in directional accuracy.

Subjects and Replications: For both alignment and compensation, _Ss_ when treated as a main effect, was a significant source of variation (Tables 8 and 9). However, replications was not a significant source of variation, indicating that there were no significant procession effects between treatment conditions.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of the study was to observe the processing demands of K information in STM. The experimental design was a treatment by subjects, complete block, randomised design with three replications for each subject. Ss were chosen from the population of physical education undergraduates.

The apparatus consisted of a joystick attached to two variable potentiometers which had the dual purpose of acting as axes of movement and transducers. The experimental task was for S to establish a number of positions and reproduce them sometime later.

There were two factors of experimental interest: information load with three levels, (2, 4, and 8 locations) and interpolated task with four levels, (immediate recall, rest for 15 seconds, IT 1 for 15 seconds, and IT 2 for 15 seconds).

Following a review of the related literature, two hypotheses were formed with both alignment (the performance measure in the mid-frontal plane) and compensation (the performance measure in the median plane) as the dependent variables. The first hypothesis stated that errors for 2 locations would be less than errors for 4 locations and that errors for 4 locations would be less than errors for 8 locations. The second hypothesis stated that errors would be the same for immediate recall and rest, and also that errors would be the same for both interpolated task conditions. It also stated that errors for the rest condition would

be less than, or equal to errors for the first interpolated task condition.

In order to investigate the data the following statistical procedures were employed: analysis of variance, Duncan's New Multiple Range Test, and the _t_ test for correlated samples.

Conclusions

Within the limitations of the study, the following conclusions were drawn.

As the K information load in STM was increased (1, 2, and 3 bits), there was a corresponding decline in recall accuracy.

The retention of K information in STM was not affected by the interpolation of redundant "kinesthetic" tasks and it was decided that this is probably due to the way K information is coded, i.e., images.

An analysis of the interpolated task main effect and the movement nature of the interpolated tasks made it possible to discuss reasons for the loss of K information from STM. It was suggested that the loss of K information from STM was not attributable to a decay theory, or an interference theory when the interfering material is dissimilar to that in store.

Recall accuracy was the same in both mid-frontal and median planes. Thus, whatever movement cues were being utilized in performing in these directions, they had no differential effect on accuracy.

Recommendations

This study has shown that the central processing demands of K information in STM are minimal and probably due to the way the information is coded, however, it has not shed light on the apparent disparity between the central processing demands of K-motor and V-motor information. Whether or not this is due entirely to central differences, or input or output differences, or some combination of these, is a problem that needs to be resolved.

The problem of interference in K STM needs further study and an exploratory study might be designed using equal attention demanding interfering tasks that differ in movement nature, i.e., a circular and a linear task.

The problem of decay in K STM also needs further study. It is suggested that the present apparatus is used and a factorial analysis made of recall accuracy using information load and retention interval (0 to 60 seconds) as the independent variables.

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APPENDIX

TESTS FOR HAND PREFERENCE

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Those _S_s who used the same hand to complete the following tests also used that hand to complete the experimental task.

1. Picking a pen up from a table.

2. Signing their names.